Received: 22 January 2022 | Accepted: 29 May 2022
DOI: 10.1111/jfb.15125

BRIEF COMMUNICATION

JOURNAL OF FISH BIOLOGY fsbi

Range expansion of a widespread Indo-Pacific haemulid, the barred javelin *Pomadasys kaakan* (Cuvier, 1830), in a climate change hotspot

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Funding information
Australian Research Council, Grant/Award Number: IN2000100026

Abstract

The authors report a first sighting of a euryhaline fish in the climate change hotspot along Australia's south-eastern coast. The barred javelin, *Pomadasys kaakan* (Cuvier, 1830) was found in the Nambucca River in New South Wales, Australia, during 2021 and 2022. Specimens were adult, suggesting they may not be transitory vagrants. The new southernmost location recorded here represents a *c.* 200 km out-of-range sighting compared to previous records, and is *c.* 380 km south of the southernmost Australian stronghold of the species in Moreton Bay, Queensland.

KEYWORDS
Australia, distribution, estuary, first sighting, fish, ocean warming

STATEMENT OF SIGNIFICANCE

Climate change in the ocean is driving changes in the distribution of fish. Understanding where and when fish are expanding their ranges may allow more accurate prediction of fish responses to a warming climate, which is crucial for effective fisheries and conservation management. This study describes a first sighting of the barred javelin in a new southernmost locale along Australia's southeast coast, an area where waterways are warming faster than the global average.

Climate change is driving the movement of organisms poleward as species follow shifting isotherms (Kelly & Goulden, 2008; Perry *et al.*, 2005). Marine fish are among the taxa which are changing their distribution the fastest (Lenoir *et al.*, 2020), often shifting by hundreds of kilometres per decade (Campana *et al.*, 2020; Champion *et al.*, 2021). Rapid movement of fishes poleward is altering the ecology of estuarine and marine systems (*e.g.*, Coni *et al.*, 2022; Luczak *et al.*, 2011) with consequences for ecosystem services (Madin *et al.*, 2012; Pinsky *et al.*, 2021). Tracking changes in fish distributions is therefore important to inform effective management of estuarine and marine ecosystems.

Often the first indication of changes in the distribution of a species is a reported sighting from an unusual locale. These "first sightings" are commonly registered by industry, citizen scientists or the general public when an unrecognised species is encountered (Fogarty *et al.*, 2017; Robinson *et al.*, 2015). Globally, first sightings are most prevalent in areas where estuaries and oceans are warming fastest, suggesting increasing temperatures play an important role in helping pioneers to establish in new locales (Arvedlund, 2009; Fogarty *et al.*, 2017). Because a few pioneering individuals can foreshadow the arrival of greater numbers in subsequent years (Fogarty *et al.*, 2017; Whitfield *et al.*, 2016), it is important that first sightings are reported

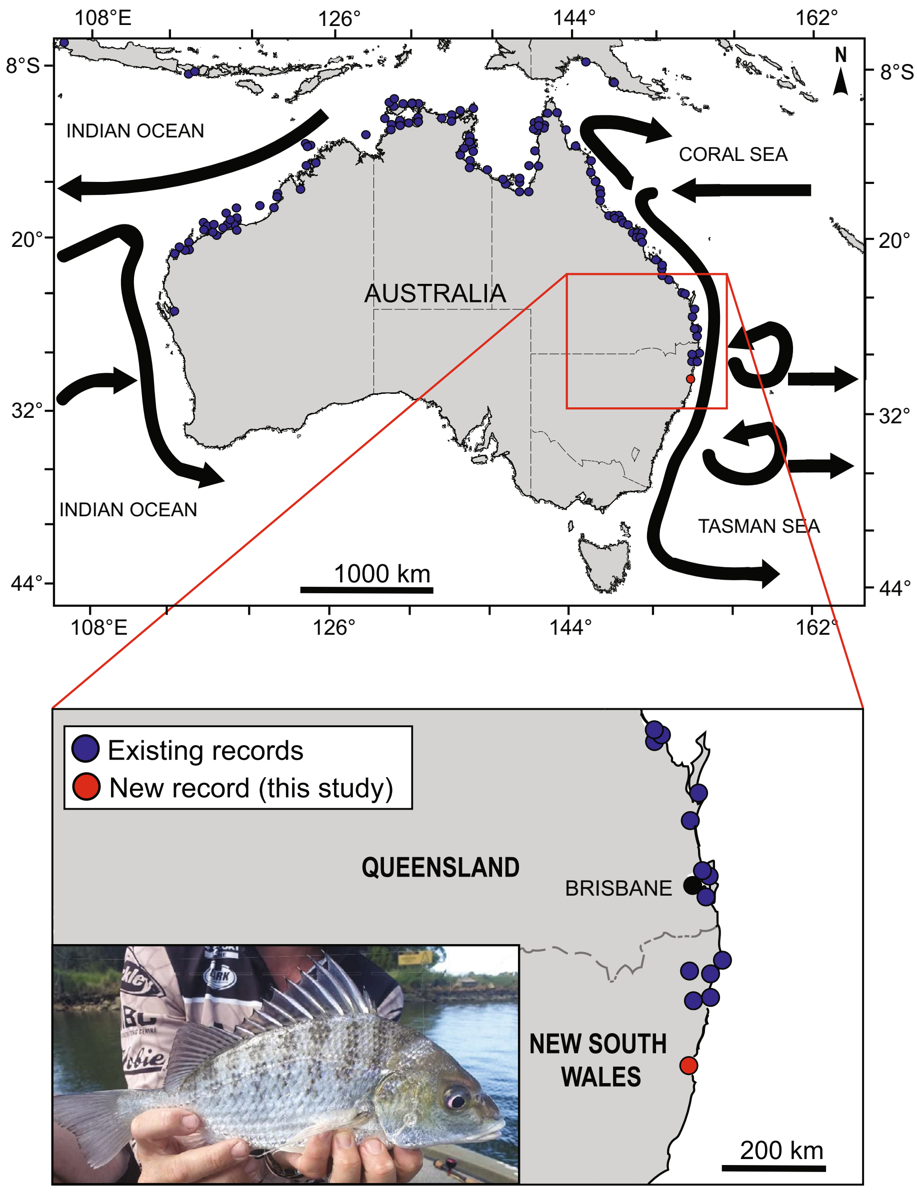

FIGURE 1 Distribution of the barred javelin, *Pomadasys kaakan* (Cuvier, 1830) (inset) along northern and eastern Australia. New South Wales record (red) indicates new southern-most location identified by this study. Records from Queensland and elsewhere in Australia, Indonesia and Papua New Guinea (blue) indicate the collection sites and sightings of *P. kaakan* collated by the Atlas of Living Australia (ALA, 2022a), and are representative of the known distribution of *P. kaakan* prior to this study. Arrows indicate dominant ocean currents; East Australian Current (east coast of Australia) and the Leeuwin Current (west coast of Australia). The ALA database for *P. kaakan* was collated from 22 databases sourced from scientific collections (Australian Museum, Queensland Museum, Northern Territory Museum, Museums Victoria, Western Australia Museum, South Australian Museum), government departments (Commonwealth Scientific and Industry Research Organisation), the Australian National Fish Collection (ANFC), community organisations (iNaturalist Australia, Ocean Biodiversity Information System, Bowerbird) and citizen scientists (ALA, 2022a). The ALA database has a more comprehensive data set for Australian *P. kaakan* than international databases (*e.g.*, FishBase, GBIF) which use only a small sub-set of the databases collated by ALA. Occurrence records for *P. kaakan* (753 records) were selected using ALA's database search engine. Default filters were applied to check for spatially suspect records, records with location uncertainty and duplicate records (removed 53 records). Records of NSW specimens (five in total) were examined individually. Location data for 700 valid records were visualised using ALA interactive maps, and exported as image files.

to alert managers to the need for additional investigation, monitoring or management intervention.

This study reports a first sighting of a widespread fish, the barred javelin *Pomadasys kaakan* (Cuvier, 1830) in a new locale outside the southernmost extent of its known range (Figure 1). *P. kaakan* occurs throughout the Indo-Pacific, with the northern limits of its range extending to the Persian Gulf (Falahatimarvast *et al.*, 2011), Taiwan, southern Korea and Japan (Hata *et al.*, 2015); eastern limits extending to eastern Papua New Guinea and Australia (Roelofs *et al.*, 2021); and western limits along the east coast of the African continent (Smith &

McKay, 1986). The southern extent of its range includes all of the coast and estuaries of northern Australia down to Shark Bay, Western Australia, on the west coast, and Moreton Bay, Queensland (QLD) on the east coast (Figure 1). Moreton Bay is considered the southernmost stronghold for the species, with the population supporting recreational and commercial fisheries (Roelofs *et al.*, 2021). The species was recorded from the Richmond and Clarence river systems in northern New South Wales (NSW) on five occasions during 1901–1959 (ALA, 2022a). There have been no additional reports of sightings or specimens collected from NSW waterways in more than 50 years despite frequent surveys by taxonomists, ecologists and government fisheries researchers during this period (*e.g.*, Gehrke & Harris, 2001; Pollard & Hannan, 1994; West & King, 1996).

One *P. kaakan* specimen was captured, measured, photographed and released alive (D. Mos, B. Mos, observation, 14 November 2021) from the Nambucca River, under the railway bridge west of Macksville, NSW (30°41′58.5″S, 152°54′56.9″E), approximately 13 km upstream from the mouth of the river (fishing licence numbers RO5548161 and RO5071795, in compliance with the NSW animal welfare laws and policies as administrated by the NSW Department of Primary Industries). A second *P. kaakan* was captured, measured, photographed and released alive at the same location (D. Mos, observation, 17 March 2022). The capture location was compared with previous reported locations of sightings or collections of *P. kaakan* in Australian waters obtained from ALA (Atlas of Living Australia), FishBase, GBIF (Global Biodiversity Information Facility) and published literature. The Nambucca River is *c.* 200 km south of the previous southernmost reported locale for *P. kaakan* in the Clarence River, NSW (Figure 1), and *c.* 380 km south of Moreton Bay, QLD (Figure 1).

The first *P. kaakan* specimen measured *c.* 36.5 cm L_S (standard length). The second *P. kaakan* specimen measured 21.6 cm L_S. *P. kaakan* reaches maturity at 20–30 cm (Falahatimarvast *et al.*, 2011), suggesting both specimens were likely sexually mature (*i.e.*, adult).

P. kaakan has similar morphology to four congeners which co-occur with *P. kaakan* along the north-eastern coast of Australia. In particular, *P. kaakan* could be misidentified as the silver javelin, *Pomadasys argenteus* (Forsskål 1775) or the blotched javelin, *Pomadasys maculatus* (Bloch, 1793), which are both recorded as occurring as far south as the QLD-NSW border (ALA, 2022b, 2022c). *P. kaakan* can be differentiated from congeners by having differences in spine counts, morphology and position of the opercle, and colouration (Hata *et al.*, 2015; McKay, 2001). Identification of *P. kaakan* specimens from Nambucca River was confirmed by the presence of 12 dorsal spines and 14 soft rays, the opercular posterior margin not extending past the midpoint of the pectoral fin insertion, a distinctive dark barred pattern and golden-yellow colouration, and a lack of prominent dark spots or blotches in the dorsal fin or on the dorsal flanks (Figure 1). The capture of the specimens was also reported to the Range Extension Database and Mapping project (redmap Australia, 2022a, 2022b) where species identification was independently verified by Dr. Tom Davis of the NSW Department of Primary Industries (T. Davis, pers. Comm., 17 November 2021, 5 May 2022). High-resolution photographs of both *P. kaakan* captured from the Nambucca River were deposited in an open access online repository (Mos & Mos, 2022), though it is acknowledged that the lack of a preserved specimen or genetic sequences hampers additional verification of the identity of the specimens.

The south-eastern coast of Australia has been identified as a global warming hotspot, a region experiencing greater increases in temperature than the global average (Hobday & Lough, 2011). This study adds to a growing list of species recorded moving south in this region (*e.g.* Mos *et al.*, 2017; Robinson *et al.*, 2015). It is possible that warm, shallow habitats within the estuary have helped *P. kaakan* to overwinter in the Nambucca River at the southernmost extent of its newly expanded range, similar to the way in which the river swimming crab, *Varuna litterata* (Fabricius, 1798) is thought to survive in the same estuary (Mos *et al.*, 2017). Estuaries in Australia's south-east are warming at twice the rate of the ocean or atmosphere (Scanes *et al.*, 2020), which highlights the potential for these waterways to play an important role in facilitating the poleward movement of tropical species in the region.

A common trend among fishes that are extending their ranges along the south-eastern coast of Australia is that southernmost populations occur through intermittent recruitment of larvae and juveniles which survive to adulthood under benign seasonal conditions (Figueira & Booth, 2010). It is unclear whether *P. kaakan* is also recruiting to the Nambucca River early in their life history as the individuals reported in this study were adult. Nonetheless, *P. kaakan* appear to be non-migratory as adults (Garrett, 1997). Additional surveys are required to understand which life stages are present, as well as the persistence of populations through time. Any population of *P. kaakan* in NSW is unlikely to be self-sustaining because a low population density and subtropical/temperate climates typically inhibit reproduction by tropical fish in NSW (Figueira & Booth, 2010). Intermittent recruitment from northern populations may also explain the *c.* 2 degrees of latitude gap between the Nambucca River, NSW and previous records in Northern NSW and southern QLD (Figure 1).

As the oceans and atmosphere warm, the East Australian Current (EAC) is strengthening and flowing further south (Ridgway & Hill, 2009). A strengthening EAC is likely to transport greater numbers of *P. kaakan* to NSW, and this, combined with warming oceans and estuaries (Hobday & Lough, 2011; Scanes *et al.*, 2020), may see increased numbers of *P. kaakan* establish in the region in coming decades, a repeat of the trend that is already occurring among other marine species (*e.g.*, Champion *et al.*, 2021; Robinson *et al.*, 2015). The ecological consequences are difficult to predict, and warrant investigation given the ecological impacts of fish range expansions globally (*e.g.*, Coni *et al.*, 2022; Luczak *et al.*, 2011).

This study is not the first to identify an expansion in the Indo-Pacific distribution of *P. kaakan* during the 21st century. Hata *et al.* (2015) reported the capture of an adult *P. kaakan* near Kasasa on the west coast of the Satsuma Peninsula, Japan, in 2014. The closely related *Pomadasys commersonnii* (Lacepède, 1801) is also expanding its range along the south-east coast of the African continent (Whitfield *et al.*, 2016). It is interesting that the regions where

P. kaakan is expanding its range are global warming hotspots, with strengthening ocean currents (Hobday & Pecl, 2014). The range expansions of *P. kaakan* in multiple locations could present an opportunity to compare the way in which climate-driven changes in distributions vary according to geographical, environmental, genetic or other factors. Studies comparing intraspecific range expansion rates in terrestrial species have generated new insights into the ways in which mammals and plants respond to changing climatic conditions (*e.g.*, Eller *et al.*, 2017; Pacifici *et al.*, 2020). To the authors' knowledge, no studies have compared range expansion rates in different locales using a marine fish.

Given the rapid warming trend and tropicalisation of aquatic ecosystems in Australia's south-east, the first sighting of *P. kaakan* in a new locale *c.* 200 km south of previous records highlights the need for additional monitoring of estuarine ecosystems to fill knowledge gaps about the ways in which increasing recruitment of tropical estuarine species may affect subtropical/temperate estuary ecosystems.

ACKNOWLEDGEMENTS

B.M. was supported by an Australian Research Council DAATSIA fellowship (IN2000100026). Open access publishing facilitated by Southern Cross University, as part of the Wiley - Southern Cross University agreement via the Council of Australian University Librarians.

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How to cite this article: Mos, B., & Mos, D. (2022). Range expansion of a widespread Indo-Pacific haemulid, the barred javelin *Pomadasys kaakan* (Cuvier, 1830), in a climate change hotspot. *Journal of Fish Biology*, *101*(3), 736–740. https://doi.org/10.1111/jfb.15125